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CONSOLIDATED CAB DISPLAY: A SUMMARY REPORT OF THE PROCESS AND THE RESULTS OF THE CONSOLIDATION OF CRITICAL AND SUPPLEMENTARY TERMINAL AREA AIR TRAFFIC CONTROL INFORMATION FOR DISPLAY PRESENTATION

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FINAL REPORT

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16. Abstract

This report describes the work performed within the Systems Simulation and Analysis Division, ACT-200, to produce an engineering requirement for a terminal area display system for field implementation by the Airway Facilities Service. The report details the basic project efforts to define a data display system to consolidate many of the Terminal Radar Approach Control Facility (TRACON) and tower cab controller's indicators, displays, alarms, controls, status lights, weather data presentations, etc., to reduce physical size, improve work station efficiency, and enhance the management and use of Air Traffic Control (ATC) oriented data. The report covers the data collection process; the requirements determination process; the technology assessment performed; the design, development, and validation of certain hardware/software components; a risk assessment of the unique aspects of the system design; and the engineering requirement form. The end product of this portion of the project was FAA-ER-500-007, which led to selection plan No. 11-78 (FAA Order 4405.10A), "Consolidated Cab Display (CCD)."

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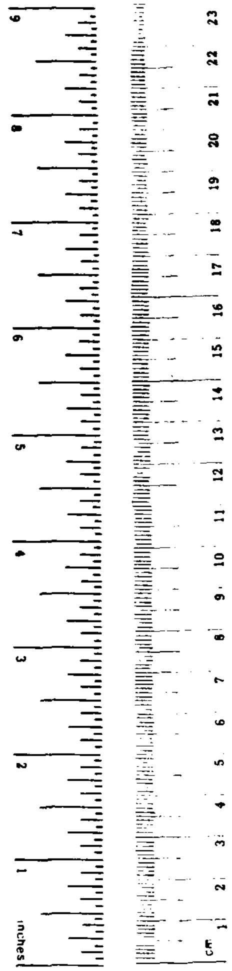
METRIC CONVERSION FACTORS

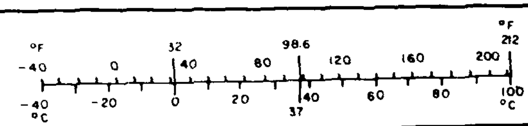
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

Acknowledgement is made to the contributions of D. Stone, L. Czekalski, K. House, P. Rempfer, G. Bishop, and to others from the Airway Facilities Service, Air Traffic Service, System Research and Development Service, Transportation Systems Center, and the FAA Technical Center, who, in the spirit of interservice cooperation, enabled this effort to reach a successful conclusion.

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INTRODUCTION

OBJECTIVE.

The objective of this project was to prepare an engineering requirement for an Air Traffic Control Tower (ATCT)/ Terminal Radar Approach Control Facility (TRACON) consolidated information processing and display system for certain types of air traffic control and status information, including information for maintenance purposes.

Federal Aviation Administration (FAA) Technical Center responsibility included the preparation of the complete engineering requirement which included the display and data entry subsystem, the central processing subsystem, the remote sensing and processing subsystem, and the interface subsystem. In addition, a detailed operational description in the form of requirements was to be incorporated as part of the engineering requirement.

The Systems Integration Branch, ACT-230, was specifically responsible for (1) the development and documentation of the requirements for the display and entry functions, (2) the display and entry subsystem hardware, (3) the assurance of operational performance integrity, (4) the determination of which one of the present functions, operations, and data were to be included in the system, and (5) the establishment of pertinent central processor requirements necessary for the assurance of the operational performance.

BACKGROUND.

In accordance with a letter of agreement among the directors of the Airway Facilities Service, Systems Research and Development Service, and the Technical Center, dated March 1978, the 1978 SRDS-sponsored program effort in 219-151-100, Advanced Concept Development Program, was redirected from advanced tower development studies to a near term, fast response effort to apply available tower and TRACON developments to the problem of consolidation: to determine, recommend, and detail a "best" system solution for problems of console space, multiplicity of display devices, alarms, indicators, controls, and data availability for towers and TRACON's.

Most navigation, communication, meteorological, and lighting aid equipment and facilities have been developed, installed, and maintained independently. As such, each has had its own operational monitoring and display hardware, as well as its own dedicated cabling. As a result, the available air traffic control tower cab and TRACON work surface and console surface areas have become saturated with a variety of instruments and displays. Because of such a proliferation of different indicators, alarms, controls, and displays required to be monitored or referenced continuously, the Air Traffic Service (AAT) has expressed great concern over the impact on present workload and operations activity, as well as concern over the impact of the installation of the expected near-term new tower and TRACON hardware.

Similarly, in the area of collecting, distributing, and acting on the required certification and maintenance data, the Airway Facilities Service (AAF) personnel are becoming inundated with additional equipment, systems, and operations parameters that also have significant impact on maintenance service efficiency.

In an effort to address these air traffic and airway facilities problems, AAF-400 and AAF-500 proposed a program (reference 1) in the FY-79 Facilities and Equipment (F&E) budget to (1) consolidate the air traffic operational status displays in the air traffic control tower cab and TRACON, and (2) centralize airway facilities maintenance monitoring at several major hub airports.

This was to be accomplished in three stages: (1) a conceptual design and documentation phase, (2) a selection of one of several requested technical proposals to accomplish the engineering requirements, and (3) an implementation phase at selected sites.

The first phase proposed to utilize the expertise at the Technical Center in two areas: (1) to develop a system mockup or prototype where possible, and (2) to evaluate over a short period of time a number of concepts for the consolidation of Air Traffic Service status information and Airway Facilities Service maintenance monitoring information. The Technical Center was to focus its efforts on the development of a display and data entry system to demonstrate operational characteristics, hardware options, software flexibility, human engineering, and human factors of a practical solution for the terminal controllers.

In addition, the Technical Center was to "determine (1) the optimum Air Traffic Service and Airway Facilities Service display format, (2) the most suitable display hardware, based on the constraints of a particular operational environment, (3) the flexibility required of the associated hardware, and (4) the method of providing redundancy."

The initial draft of the work effort to be accomplished included the following list of items to be incorporated:

Instrument Landing System (ILS) Status

Digital Altimeter Setting Indicator (DASI) Status

Weather Information

Clocks (Time)

Runway Lighting System (RLS)

Approach Lighting System (ALS)

Automated Terminal Information Service (ATIS)

Runway Visual Range (RVR)

Airport Surveillance Radar (ASR)

Distance Measuring Equipment (DME)

Vortex Advisory System (VAS)

Surface Winds Information Monitoring System (SWIMS)

Visual Approach Slope Indicator (VASI)

It was anticipated by Airway Facilities Service that the initial air traffic data consolidation would involve only the status information currently being remoted to the cab and TRACON, with the addition of VAS and SWIMS. Attached to the initial draft documents was a detailed list of specific data envisioned to be included on such a display system. This list was prepared by the various Airway Facilities Service divisions for purposes of discussion. These forms of information would constitute part of the consolidation basis for the Air Traffic Service operational data.

In addition, a very extensive list of technical equipment status in the form of voltages, power, temperature, channel-in-use, and similar parameters was to be accumulated for maintenance data display purposes.

During the course of the program, additional F&E funding limitations resulted in a reduction of the scope of the initial implementation in the areas of site data communications, remote data communications, and quantity of sites included. Subsequent reviews of the estimates for anticipated contract costs resulted in a further reduction. Only two sites, Boston and Atlanta, would receive the systems for evaluation and use, and only signals that already exist

in the tower/TRACON complexes would be interfaced to the system. No remote site sensing would be included, but enough microprocessor-controlled sensing would be included to verify the remote sensing design. However, the central processing subsystem would be required to be capable of handling the entire consolidation, display, control, and monitoring system as originally configured. This would permit rapid expansion of the initial system to include remote maintenance monitoring and other specialized signal processing and control. No changes to the display subsystem and its related requirements were made.

TECHNICAL APPROACH

MAJOR AREAS.

Eleven major areas of effort were established in conjunction with the Airway Facilities Service and Technical Center program management personnel and with the Technical Center Engineering Management Staff:

1. Determine, validate, establish, and verify the data presentation requirements.

2. Conduct detailed technology reviews and assessments to determine the specific state-of-the-art for display, entry, and processing hardware and software.

3. Conduct detailed measurements, make recordings, and perform compilations of the pertinent air traffic control operations being performed in representative tower/TRACON complexes to establish a comprehensive characterization of level 4/5 towers, to determine site peculiarities, to validate operational requirements, and to aid in the project functions of data integration at the work station.

4. Research related existing, scheduled, or planned programs, and conduct studies to find and analyze systems in use which perform similar display, entry, processing, and control functions, to determine systems and design applicability.

5. Perform display and entry device development to incorporate unique air traffic control requirements, existing technology, and off-the-shelf hardware into specific FAA-oriented devices and/or specifications.

6. Collect, analyze, and determine various techniques, philosophies, and systems approaches to integrate the various forms of information and data required for presentation to the controller.

7. Establish a selection of configurations for information displays and entry devices in a cluster for a work station that incorporates all of the other devices necessary for the proper operation of the work station and the controller. Demonstrate and evaluate the various configurations using operational personnel.

8. Select a final configuration for specification purposes, validate that all functions are performed, and secure Air Traffic Service concurrence.

9. Prepare an engineering requirement describing the system, hardware and software, and operational performance to the maximum degree possible.

10. Prepare a detailed operational specification of all the operational functions to be performed by a computer-controlled data display system, by the display devices, by the entry devices, and by the operators of the system to achieve or receive all the specific operational data and information desired. This is to support item 9.

11. Prepare, under contract, suitable software to be implemented in the Technical Center's Computer Controller Interface Laboratory (CCIL) to demonstrate simulated dynamic data display for Air Traffic Service and Airway Facilities Service review. This is to support item 6.

BASIC PHILOSOPHIES.

Within each of the activity areas listed above, work efforts were performed that were guided by several basic philosophies.

1. The proposed system shall perform only the limited number of functions designated by Air Traffic Service and Airway Facilities Service, and shall include expansion only as indicated.

2. The system shall be required to operate only in the designated FAA environments and under the real-time, safety-critical conditions demanded of dynamic, concurrent air traffic control operations.

3. The system shall be required to be an application of current, existing, validated, and implemented technologies, with a limited amount of custom hardware packaging and applications software.

4. The shortest time period possible shall be utilized to produce the final documentation.

5. Techniques, hardware, and device technology shall be evaluated in detail in the lab only if they present a risk in the form that they would be applied, or create a question of functional applicability that has not been addressed in prior pertinent program efforts.

ENGINEERING REQUIREMENTS.

Because of its size, a final copy of the Engineering Requirement (ER) is not included in this report, but is available through AAF-700 (reference 2). The specific sections of the ER resulting from this effort include Part 1, Appendix 1-20, "The Operational Requirements for Entry, Display, and Display Information Processing," and Part 2, "Display Subsystem Engineering Requirements." The tables of contents for these sections are provided in the appendices. In addition, extensive input was provided to Part I, "General"; Part 3, "Central Processing Subsystem"; and Part 7, "Tower Interface Subsystem."

REQUIREMENTS ESTABLISHMENT.

In order to determine the data presentation requirements, written contact was established with all of the divisions in Air Traffic Service concerned with air traffic control procedures, activities, planning, operations, facilities, etc. Similarly, Airway Facilities Service divisions were queried concerning equipments, status types, procedures, and operations (references 3 and 4).

As part of a larger study of tower/TRACON operations, Transportation Systems Center (TSC) project support personnel in the Operations Analysis Branch, DTS-522, assembled and organized operational requirements from a number of field sites, including Boston and Atlanta.

Air traffic control personnel from the facilities and the two regions (New England and Southern) were interviewed; interests, requirements, and desires were discussed.

Written procedures, from both standard manuals and facility documents, were reviewed; and correlation was achieved with other requirements' inputs.

Factors such as ambient light conditions and physical space were reviewed using descriptions of facilities, information from prior tower and TRACON environmental studies, references from the Illuminating Engineering Society Handbook on ambient light ranges in the United States, and human factors

principles for space and visibility conditions.

From this information, basic data content, priorities, data timeliness, general format, and data groupings were determined. Human factors considerations influenced such determinations throughout the process.

TECHNOLOGY ASSESSMENT.

Review and assessment of a broad range of technologies is a continuing process that has been a part of this project, as well as preceding projects, within this program. Continuing contact was maintained with many of the major development companies in the field of displays; technical journals were reviewed both for products and indications of emerging technologies; extensive inquiries were directed to many of the computer manufacturing companies with regard to hardware, software, and firmware; seminars and symposiums were attended to maintain currency in the developmental efforts and applications engineering advances pertinent to the project which emanated from industry, academic institutions, and from the Department of Defense.

In two areas, computer architecture and computer operating systems software, detailed compilations and performance analysis were undertaken to become parts of another technical formal report. The specific details of the requirements for performance by the processors, the software, and the system as a whole, as described explicitly in Parts 1, 2, and 3 of the ER, were derived from the studies in these two areas.

Where necessary to validate specific display performance relative to special FAA requirements, individual devices were purchased and integrated into the CCIL for evaluation. These included incandescent segmented indicators, projection legend switches, plasma matrix displays, and infrared finger-touch switches.

OPERATIONS ANALYSIS.

A detailed study of Boston Logan Airport was undertaken by the Operation Analysis Branch, Transportation Systems Center. The study, documented, described, analyzed, and measured the air traffic control and airport operations performed by the facility personnel; their use of and requirements for the various supporting hardware; and their interactive activities and responsibilities for the use of certain forms of information. This study resulted in an extremely detailed and extensive report (reference 5), which helped to establish a baseline for the collection of data about terminal facilities' operations. In order to prepare a characterization of all the level 4 and 5 towers (and associated TRACONS) as part of the continuing SRDS-sponsored program effort in 219-151-100, similar studies were planned for additional sites. Atlanta's airport study (reference 6) has been underway since the spring of 1979. As more airports are studied in similar detail, the characterization of terminal facilities will become more comprehensive. Denver and Albuquerque are scheduled for FY-80.

ASSOCIATED PROGRAMS REVIEW.

A review of Engineering and Development programs and Airway Facilities Service implementation plans, which could conceivably have any bearing on the subject program, was conducted specifically to:

1. Inform program personnel of potential conflict areas.

2. Allow for early establishment of externally influenced requirements.

3. Minimize parallel program efforts.

4. Gain additional supportive information on system requirements based on the experiences of other programs.

A separate survey was conducted through selected government sources—the Technical Center library, the Department of Defense, the National Weather Service, and selected industrial systems manufacturers to find and analyze data display and processing systems that already are in use performing similar functions, in whole or in part. Applicability, in part, to the subject program requirements was reviewed to determine risk reduction, reproducibility, maintainability, cost, specific display performance level, and software pertinence.

The following FAA programs and documentation were reviewed for applicability to this program:

1. 084-752-540, Wake Vortex Avoidance System Evaluation.

2. 142-173-500, Terminal Information and Processing System.

3. 143-102-530, ASDE Controller Operational Tests.

4. 143-152-400, VICON In-Service Operational Evaluation, Phase II.

5. 144-170-820, Terminal Sustaining Engineering.

6. 154-751-160, Airport Low Level Wind Shear System Field Test.

7. 161-020-160, Impact of Cockpit Display of Traffic Information on Controller Workload.

8. 219-151-110, Terminal Weather Integrated Display System Development.

9. Subprogram 131-401, Mass Weather Dissemination.

10. Subprogram 132-402, Flight Service Station Specialist Automation.

11. Subprogram 153-451, Automatic Weather Observation System, technical data package, Interagency Agreement DOT-FA-78WAI-872.

12. Contract FA-74WA-1489, Meteorological Aeronautical Presentation System (MAPS) reports.

13. Report NA-77-75-LR, Improved Displays for Air Traffic Control Towers.

14. Report FAA-RD-77-190, Feasibility Study for Simulation of an Airport Tower Control Environment.

DEVELOPMENTAL EFFORT LEVEL.

Because of the time constraints imposed on the program and the funding limitations, no significant hardware development was undertaken. However, the development of the form of the hardware, the incorporation of various and special diverse requirements, the development of unique and detailed performance requirements, and the development of detailed methods to test the ability to meet such requirements were all developmental activities based on knowledge of the state-of-the-art in system capabilities.

This developmental activity actually produced the final expected form of those portions of the system that were not strictly "off the shelf," or had certain technological, physical, or human factors risks that needed to be assessed and minimized.

INTEGRATION PHILOSOPHY.

The process of integrating the information and controls required in the system into a small number of display devices (one device, in the limit) included a review of various methods and methodologies to accomplish this integration, followed by mockups, pasteups,

simulation, and informal and formal evaluation by subjective and objective means.

Concepts of data integration, including full tabulation, graphic portrayal, paging, display by exception, overlay, multiple display, multiple device, and composite display, were reviewed and studied. The advantages and benefits of each were selected as part of the integration process, and the concepts they represented were incorporated based on compatibility, ability to meet requirements, adaptability to the air traffic control functions, performance assurance, and human factors limitations.

An iterative process was followed that permitted the form of the hardware to be gradually tailored to the data necessary to be presented, and permitted the data to be modified, ordered, prioritized, or expanded to meet the capabilities and limitations of the hardware. The anticipated costs of the resultant end products, as well as the cost-free benefits, accomplishments and capabilities of the processing, display and entry system, due to integration, were important considerations. They were not, however, the primary factors. ATC operational utility remained as the primary, overriding consideration.

Several approaches and methods for meeting the information needs of the controller were formulated and presented to operating controllers from the Technical Center and from two FAA Regions where installations are planned, and to representatives of the Air Traffic Service in Washington. These methods were determined to be the ones that satisfied the technical, environmental, and operational requirements, though still in varying degrees. Since several contained technologies that had not been implemented in ATC systems, it was desirable to expose ATC personnel to the new device technologies in a nonprejudicial manner so that each could be evaluated in its proper environment and performing at its expected level.

Evaluations were conducted on:

1. A single cathode-ray tube (CRT) display with 24 and 36 lines of 64 and 80 characters per line. Multiple functions were portrayed, and multiple pages of data were utilized.

2. Multiple CRT displays, with contents as in item 1, each dedicated to specific functions and each capable of being paged.

3. Dedicated function/information displays utilizing a CRT, discrete character indicators with segmented incandescent filaments, light-emitting diodes, liquid crystal segments, rear projection displays, and segmented and dot matrix gas discharge indicators.

4. A programmable, multifunction array display, specifically a dot matrix green plasma device that is physically small in size.

5. An up/down preprogramed counter/display.

6. A computer controlled multiple legend, rear projected display indicator integrated with an entry switch.

7. A finger-point, data-select action on a CRT.

Using these devices in various combinations, simulated work stations were evaluated by stepping through the routine processes and procedures that require the use of such information. Also, the nonroutine and especially critical events and activities were simulated, and the ability to obtain the data in the form required was determined.

RESULTS

FINAL CONFIGURATION.

A final configuration of displays and entry devices was selected, implemented, and validated.

The configuration included the following (with a synopsis of the rationale for the choice made):

1. Critical data which are required to be viewed, scanned, utilized for other decisions, and often conveyed to the pilot, are sufficiently "critical" in importance that they must be available all the time, cannot be paged for, and cannot require any action by the controller to get the data. They must not require extrapolation, interpolation, conversion, modification, or partial deletion. They must be rapidly and clearly visible under all ambient conditions, from night blackness to direct sunlight or skylight reflections. They must be legible across the tower (15 to 20 feet). They must clearly indicate alert conditions of specific critical data. These major requirements and numerous minor ones are best met in a fixed format, segmented character, incandescent filament display. No other device type can satisfy the operational needs as determined. Hence, a "critical" display of the this type is made part of the work station for the listed critical functions and data listed below (see figure 1):

a. Hours, minutes, and seconds of real time.

b. Barometric pressure.

c. Center-field wind direction, velocity, and gusts.

d. Runway designations for up to three active runways.

e. A safe approach distance spacing from the Vortex Advisory System for three runways.

f. The failure status of the prime or backup approach lighting system and the instrument landing system (and its component parts such as the markers) for three runways.

g. The runway visual range (RVR) visibility figures for up to three RVR's per runway for each of the three runways, and the coded status of the units.

h. The setting level of the approach lights.

i. The setting controls for and the numbers that indicate the RVR thresholds for each of the RVR's.

j. Low level wind shear boundary location, velocity, and direction.

k. Space for short weather messages (50 to 60 characters) in the National Weather Service (NWS) message format, but without meteorological information already displayed as above. This message would normally be equivalent to selected portions of Service A local weather.

2. Almost all other forms of information that might be necessary or desirable to present to the tower controller are to be presented on a "supplementary" display. This supplementary display would have sufficient flexibility to permit alphanumerics and symbols to be displayed at all character locations, and would be adequately legible at reference viewing distances of 2 to 3 feet in tower cab ambients.

In order to eliminate problems of clutter and data location, multiple pages of data with 512 characters per page (16 lines of 32 characters each) were determined to be more useful than 1,920 characters per page (24 lines of 80 characters each) or more.

The smaller character quantity enables the use of larger characters which enhances legibility and allows higher refresh rates on the display (up to 100 hertz (Hz) noninterlaced, with no excessive bandwidth requirements) to enhance high ambient viewing. The small

size television rectilmear raster display is the best device for this purpose, and the 9-inch diagonal size results in 0.25-inch high characters, a very desirable size (see figure 2).

The information to be presented on the various pages can include, as a minimum:

a. Notice to Airman (NOTAM)

b. Satellite weather

c Navaid status for all runways

d. RVR for all runways

e. Special messages

f. Phone numbers

g. Reconfiguration sequences

h. A backup page of critical data

i. Indexes

The ability of the CRT to be enhanced to provide adequate contrast has been established in several of the Technical Center programs, which the author has been involved in, that dealt with display development for high ambient use. One was for the development of the bright radar indicator tower equipment (BRITE) systems' CRT, another was for the development of the display for the Flight Data Distribution System for flight data handling in a tower, and a third was for the development of high contrast supplemental displays for Air Route Traffic Control Center (ARTCC) use.

For larger quantities of data than a "critical" display can properly handle and for the described ambient, the raster scan proved to be the most advantageous.

3. The TRACON environment demanded a display of rather exceptional properties:

a. Very good legibility

b. Ease of reading in a dark environment

c. Minimum area and minimum depth

d. High reliability

e. Flexibility of character display

f. A green display color for minimum fatigue

In addition to the display requirements as listed, the device has to provide most of the critical data as determined for the "critical" display, plus permit a portion of the display to be paged to display supplementary information.

While a very small CRT might be utilized (approximately 6 to 7 inches diagonal), the character legibility and display reliability of such a device is not adequate for the rapid reference use of the display in the TRACON.

A green-emitting gas discharge ("DC" plasma) dot matrix display was selected as the best display device. With a display package size of approximately 7 by 7 by 3 inches, including electronics, and capable of displaying 16 lines of 32 characters (512) in a 6- by 6-inch display area, it can safely be placed in numerous locations in and about a TRACON work station. The front surface is glass covered with plastic, and it can be used as a writing surface if the display is mounted horizontally in a console ledge.

Character height is nominally 0.21 inch (5 millimeters) and evaluation indicated superior legibility for the TRACON viewing requirements of up to 10 feet.

Industry tests and commercial applications indicate a useful display life of at least 30,000 hours. With low power requirements, component life and

reliability appears well assured. As with CRT displays, the plasma panel itself is plug-in and replaceable (see figure 3).

4. The supervisory and maintenance activities required to be performed through the use of a data terminal (enter, delete, alter, or monitor data for operational use) will require a terminal that is moderately sophisticated but essentially identical to many devices already marketed for computer input/output (I/O) and control purposes. The only requirement that has been added relates to the front surface treatment of the CRT in the terminal. This treatment is for antireflectivity and can be accomplished at minimal cost with no impact to the terminal's electronic operation. The antireflectivity turns the marginally unacceptable contrast levels into comfortably adequate and acceptable performance levels for use especially in the cab ambient.

5. The analysis of work functions and their frequency indicated that the requirements for "control" of navigation and approach lights by the local controller should not be integrated into any of the other display/entry devices because of adverse performance interference. The combination of all the controls for all the pertinent lights for three runways, with a status indication of each of the lighting systems, was determined to provide, in a concise package, all the associated functions in a noninterfering, nondegrading form. In accordance with the concept of providing information on only three runways per operating position, three sets of status and control buttons are provided as rapid I/O devices (see figure 4). A two-button sequence—one for the level of action to be taken (lighting level) and one for the device or system to be affected—is utilized. This is a practical, human engineered design that is deemed to provide optimum performance, chosen between the two limits: (1) fixed format, with one button for every single kind of action possible—numerous buttons (reference 7), and (2) totally selectable format, with many button presses in a sequence—very few buttons.

By system design, an action to be accomplished is keyed into the computer with one or two key strokes. The legends on the key caps are computer controlled and do not indicate a change to the desired condition until the condition is achieved and sensed as achieved.

The combination of the entry switch button and the computer-controlled legend is accomplished in a commercially available product called a PROSWITCH™, which is a nonmechanical, high reliability, high legibility indicator designed to offer 12, 24, or 48 digitally selectable legends in a 1- by 1- by 4-inch package.

As conditions demand, runway use undergoes reconfiguration; runway and lighting designations are automatically changed on the controllers displays and control panels via automatic reconfiguration sequences in the computer, initiated by a choice of the appropriate runway usage configuration. In addition to automatically modifying the meaning of data at the working positions, the computer can provide a time-ordered prompting list on one of the supplementary display pages for the actual sequence to accomplish the reconfiguration.

SPECIAL OPERATIONAL SOFTWARE PHILOSOPHY.

One of the requirements that emerged through most of the operational discussions was that the CCD system user (the air traffic controller), aside from updating displayed data, needed to be able to make certain changes in the format, content, importance, priority, and value of the information routinely in use through the display system and as presented to him by the computer. The changes would be partially adaptive, partially preferential, partially

convenience, partially corrective, and partially experimental. The point made, however, was that without a routine, easy way to reformat certain types of data as daily or even hourly demands changed, a psychological barrier to user flexibility would seriously inhibit the confidence development, and user acceptability, of this critical system.

In 1975, the FAA's System Research and Development Service sponsored a project at Washington ARTCC called MAPS, to provide supplemental data to en route controllers. Part of this effort was to investigate, develop, and program limited capability to allow the controller to make simple modifications of his display formats based on his own preferences. The contractor individual who prepared the software for the MAPS system, K. Dilkes, subsequently became a subcontractor through the Small Business Administration and Mandex, Incorporated, on contract DOT-FA-78NA-5505 (reference 8). The contract was awarded to help develop, to a high detail level, the operating system requirements, including "flexible format display" for the CCD Engineering Requirements.

The extensive flexibility, both for the user/controller and for the tower/TRACON complex, comes from a software program that handles incoming data in an innovative way, filters and stores data, extracts it in a proper and rapid fashion, and reassembles it for display purposes. But, it also includes the ability and the special interactive capability for computer aided and prompted data manipulation for display purposes. It is not the controller's choice as to whether or not certain forms of data must appear on his displays, but only where, how, and with what forms of alert indication it will appear. This flexibility is not designed to destroy site-to-site uniformity for the Air Traffic Service; on the contrary, it encourages data "content" uniformity while allowing data "format" flexibility on a safe, fast, convenient, and control-position-adaptation basis. Another aspect of this flexibility is the inherent software ability to accept new terminal-related expansions, such as runways, equipment, procedures lists, weather sources, navigation aids, and other data sources that would require modification of a data display. New items can be added by the user, without a programer's entries, at any time with the computer's help. This capability is intended as a vital parallel for the expandability of the computer and other hardware.

By requirement, the system must be expandable to handle the data display from those operational functions which were "undefined" as of the ER date; this would appear as an impossibility, especially with respect to computer sizing, speed, and performance, and display and control system performance. By proper choice of system architecture, however, this requirement can be and is being met (reference 9, par. 3.2.1, 3.4.1, and 3.5 of Integrated Potential Requirements for En Route ATC Computer System, A006, AAF-700).

By expanding on the original MAPS experiences, it became possible to provide, within the CCD ER, a complete, detailed set of operational specifications which covered the following: exactly what performance was to be expected for specific input stimuli and how to test for this performance achievement, what priority and order was to be followed, what software mnemonics were to be applied, what sequences of work input were to be used, etc. The entire set of ATC operational performance requirements for the whole CCD was divided into 15 demonstrable units (DU's), each of which tested and demonstrated completely the performance of the entire CCD system as far as the ATC user would be concerned. The orderly, sequential completion of the 15 "DU's" was both a measure of the technical performance of the CCD system and a contractual indication foi the ATC user that all the operational functions,

including the use of flexibility formatting, were performed properly.

In its simplest form, the detail of the ER, and especially of the "Operational Specifications" (as witnessed by the content of the Appendix 1-20 to Part 1 of the ER) resulted from an FAA knowledge of the exact performance, in great detail, that its own operating services required. To leave much of this detail up to a contractor, who could never be as experienced in ATC system operational performance as the FAA, was deemed unnecessarily risky and uneconomical. By benefiting from specific prior FAA experiences, the authors of the ER could validly include such details and requirements and, in effect, remove much of the research and development risk that a contractor would be exposed to in dealing with the design of an ATC data management and display system.

Because of its size (170 pages), Appendix 1-20 to FAA-ER-500-007/1 is not an enclosure to this report, but is readily available through normal documentation sources, as well as Airway Facilities Service (AAF-740). It serves as an embodiment of the operational specifications and places them, as a complete set, in the form of requirements to be met by the contractor. The arbitrary aspects of contractor responsibility in the ATC operational performance of the CCD are removed.

CONCLUSIONS

It is concluded that:

1. The Engineering Requirement (ER) prepared as the official output of the project is, in both form and substance, a document suitable for the purpose of system procurement, as witnessed by the signatory approvals of the appropriate Service Directors, including the Associate Administrator of Air Traffic and Airway Facilities (ATF-1), and the approval by the Administrator of the Federal Aviation Administration (AOA-1) of Selection Plan No. 11-78 (reference 10) for the implementation of Consolidated Cab Display (CCD) systems.

2. The process used to establish, develop, validate, and verify the requirements for the CCD system is a viable, responsible, thorough, and necessary process to follow when a system is to be designed for air traffic control (ATC) operational use.

3. The use of detailed operational specifications, expressly prepared to describe the methods, forms, procedures, and expected results of operational utilization of all the operational functions of a human-operated display and control system, is the most satisfactory method of assuring operator approval, contractor comprehension and compliance, and completed system functional integrity.

4. The use of different types of display devices, as described, is not to be regarded casually, especially when logistics, maintenance, and training aspects emphasize commonality. However, since technology permitted it, cost did not prohibit it, and operational performance requirements left little room for compromise, the design choices had to be made in favor of the system user—in this case the ATC specialist.

5. The state-of-the-art of computer systems for fail-safe, real-time use with no loss of data is comfortably and adequately high for FAA's needs.

6. The concept of a system design that permits uninterruptable system expansions, both in hardware and software, is very viable, and has been implemented in commercially available computer systems.

7. Implementation of the concept of a fully flexible format capability to be utilized by an ATC specialist is critical to controller acceptability of data management and display systems.

8. The interservice agreement process that was used enabled close cooperation, planning, work efforts, and approvals by the participants of the project. The timely completion of the documentation resulted in a high level of appropriate service approvals.

RECOMMENDATIONS

It is recommended that:

1. The interservice agreement process be utilized and encouraged under the guidelines and example of the Consolidated Cab Display (CCD) effort.

2. The requirements determination process that was followed be encouraged and recommended for other programs that relate to man-machine systems integration.

3. Detailed operational specifications, similar to those utilized in the CCD Engineering Requirement (ER), be required as part of any ER or specification that relates to man-machine systems, as both an indication of the detail of the Federal Aviation Administration's (FAA's) knowledge of its requirements and an indication of the reduced risk role of the contractor.

4. The CCD ER, in form and substance, be the basis for a terminal data management system for FAA implementation.

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6. Atlanta Terminal Information Processing System (TIPS) and Consolidated Cab Display (CCD) Installation/Integration Analysis Draft Report, DTS-541.

7. Grambart, J. E., Human Engineering Analysis of Airport Lighting Control Panels, and Proposal for a New Design, FAA-RD-72-93.

8. Detailed Operational System Requirements Preparation, (Statement of Work), DOT-FA78NA-5505.

9. Integrated Potential Requirements for En Route ATC Computer Systems, A006, AAF-700.

10. Selection Plan No. 11-78, FAA.

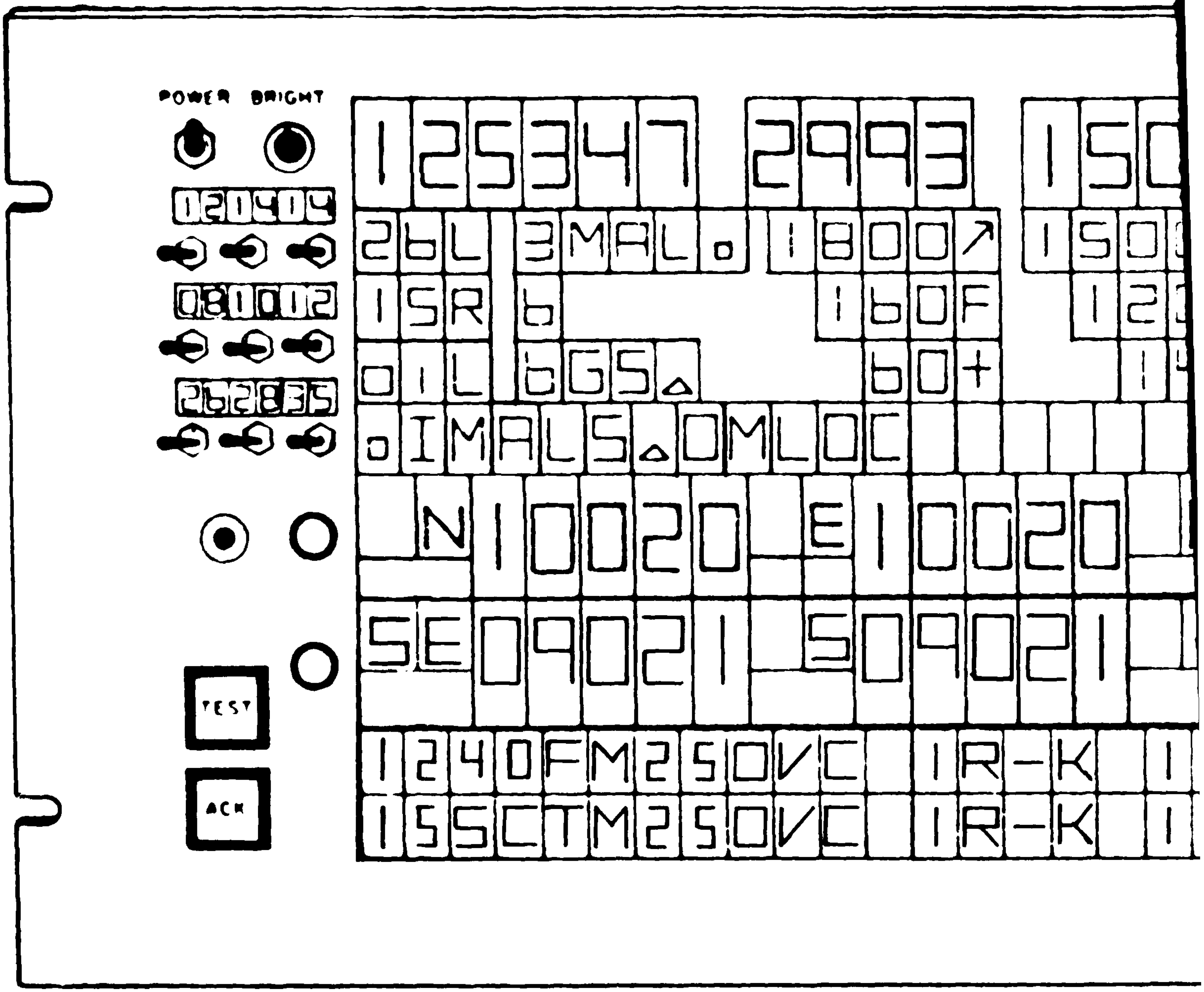
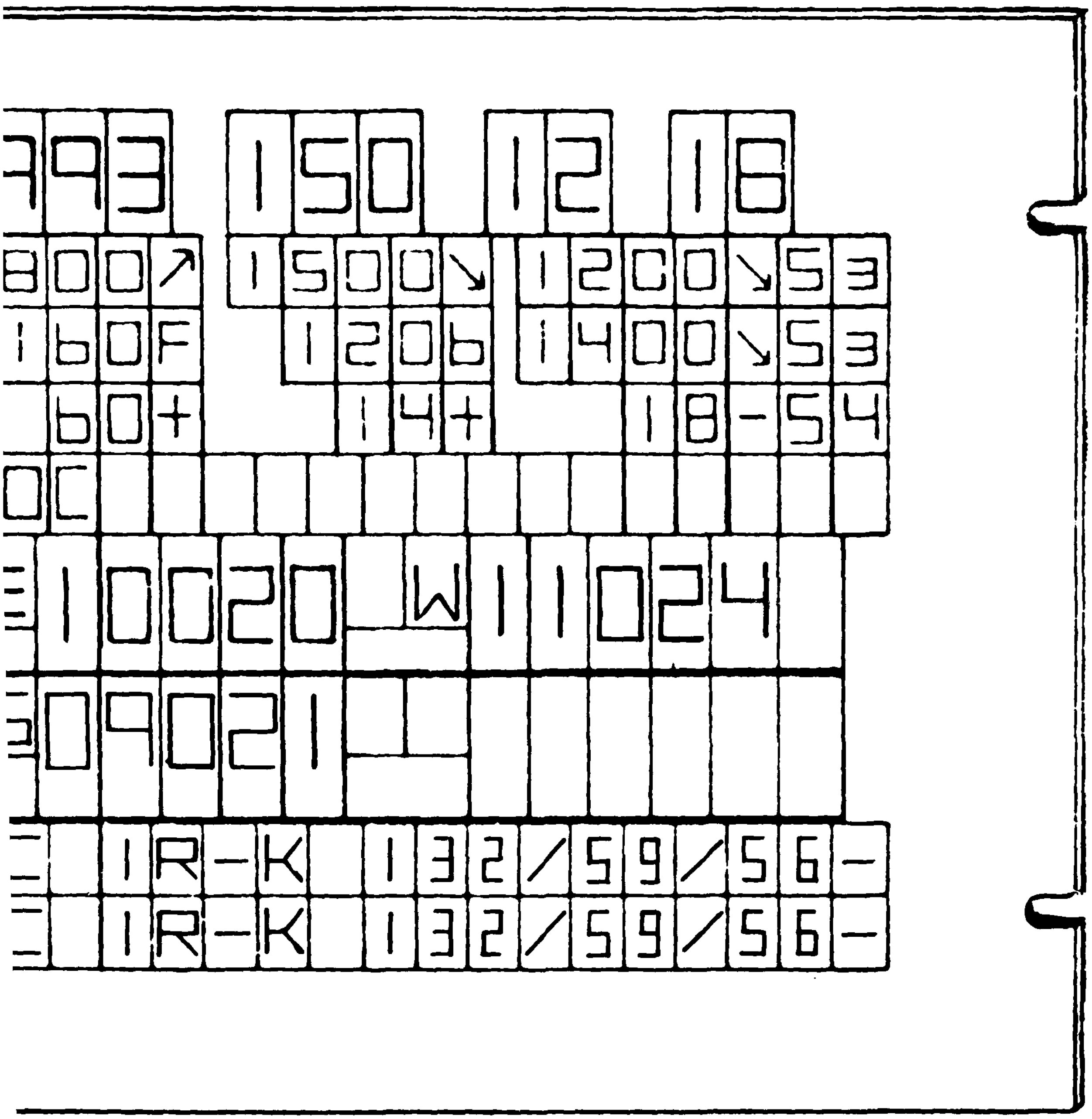


FIGURE 1. CRITICAL DISPLAY—FRONT PANEL LAYOUT (FULL SC



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›LAY—FRONT PANEL LAYOUT (FULL SCALE)

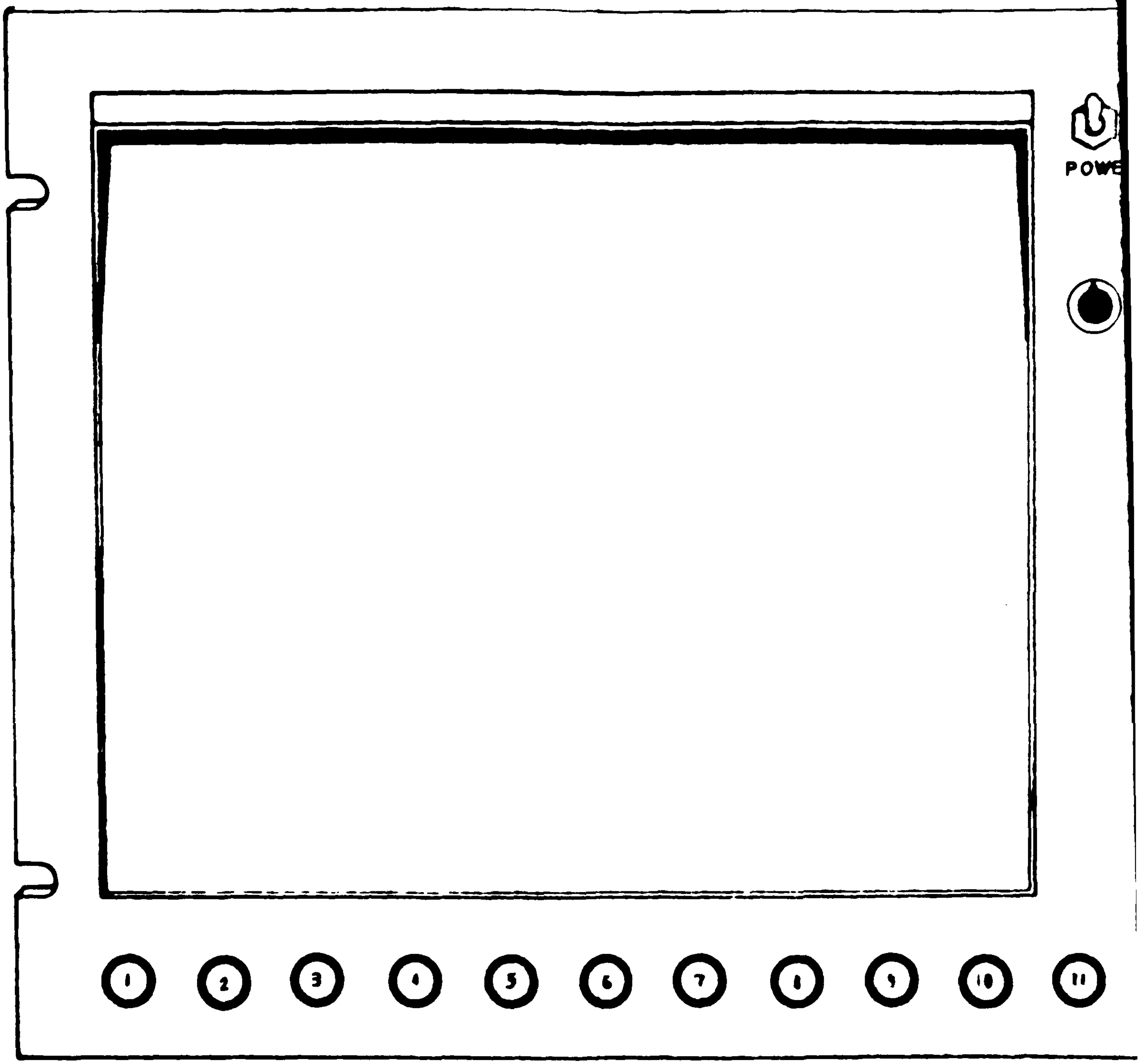
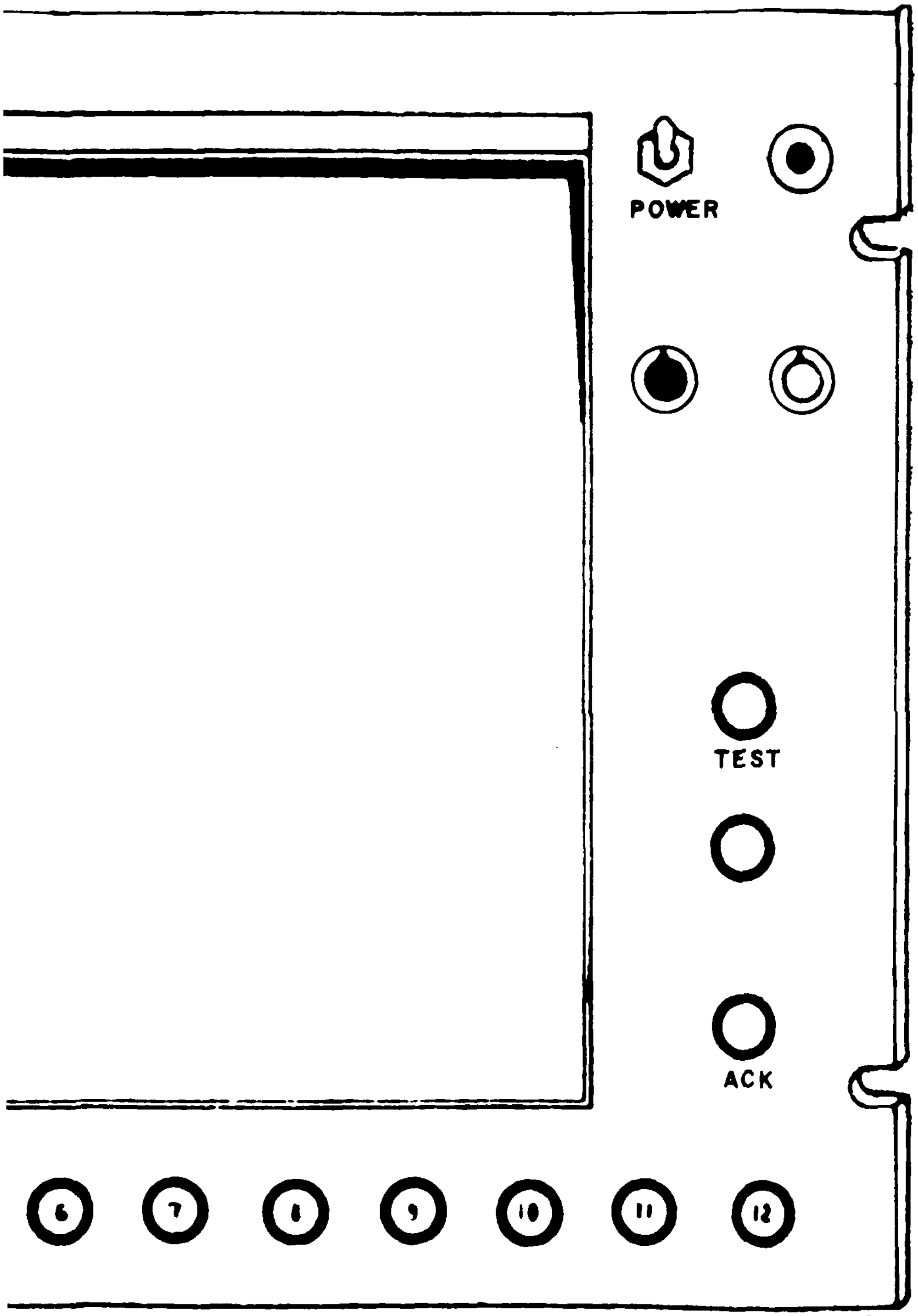


FIGURE 2.   SUPPLEMENTARY DISPLAY (FULL SCALE)



JPPLEMENTARY DISPLAY (FULL SCALE)

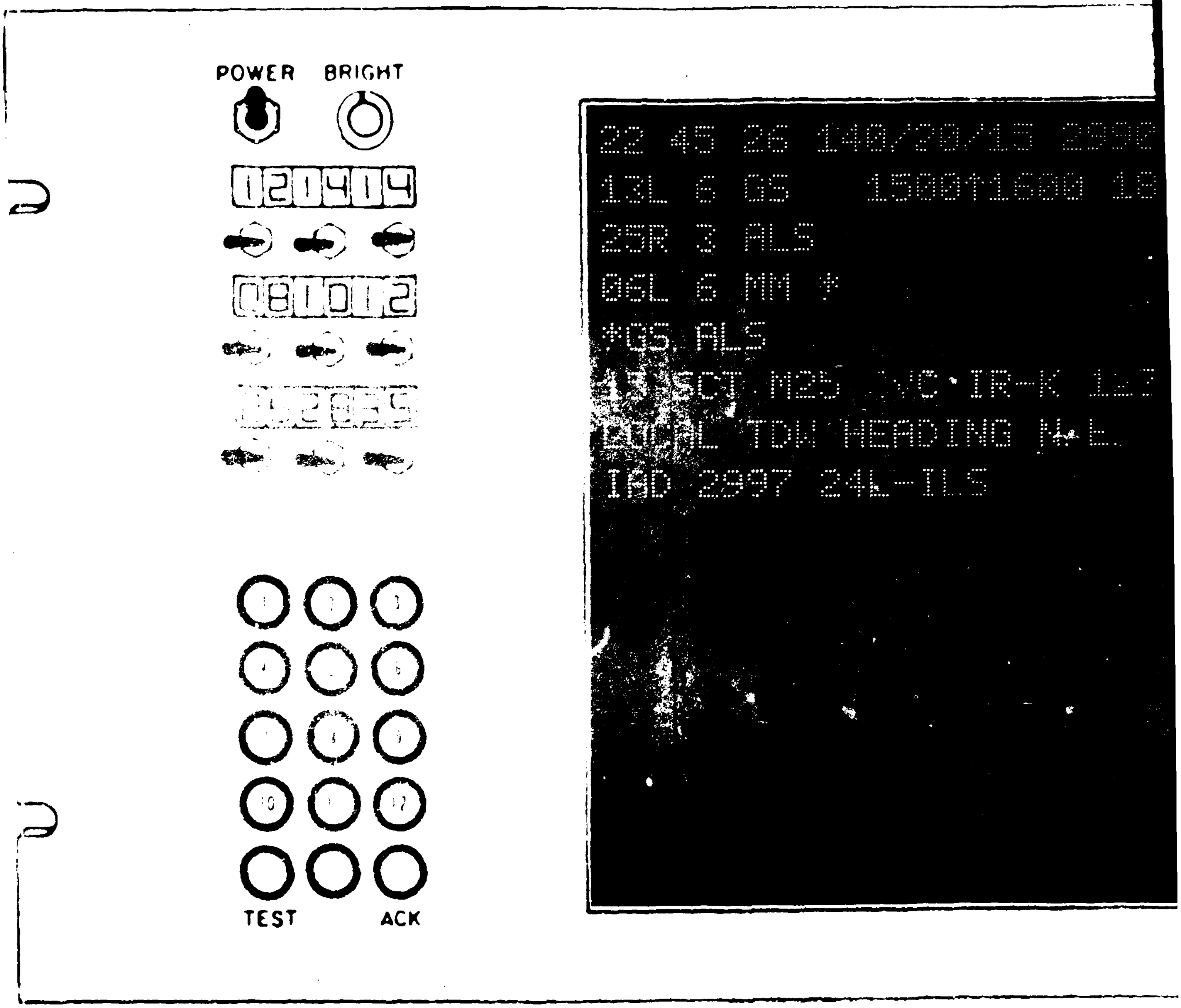
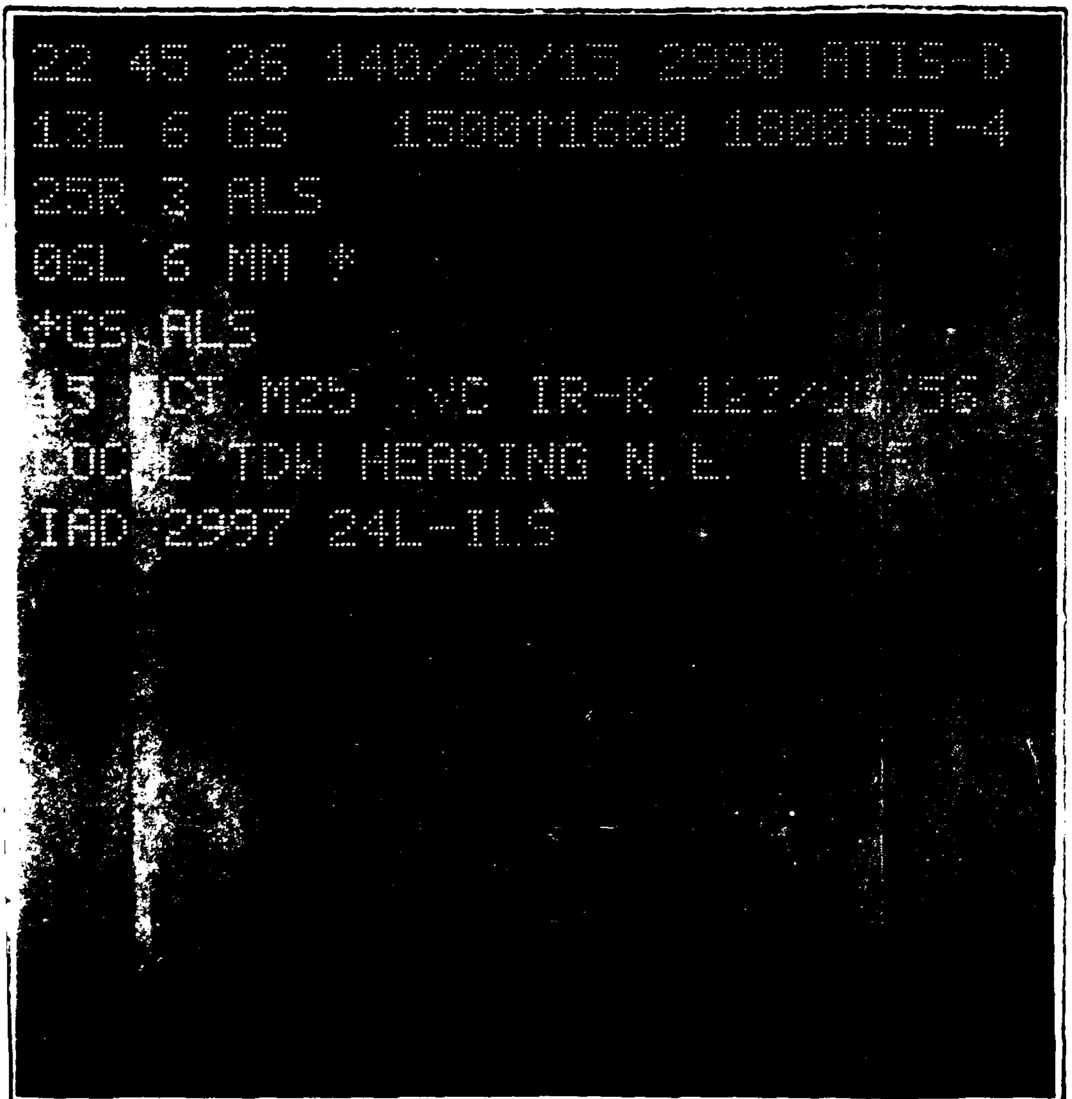


FIGURE 3. TRACON DISPLAY—PANEL LAYOUT (FULL SCALE)



ACON DISPLAY—PANEL LAYOUT (FULL SCALE)

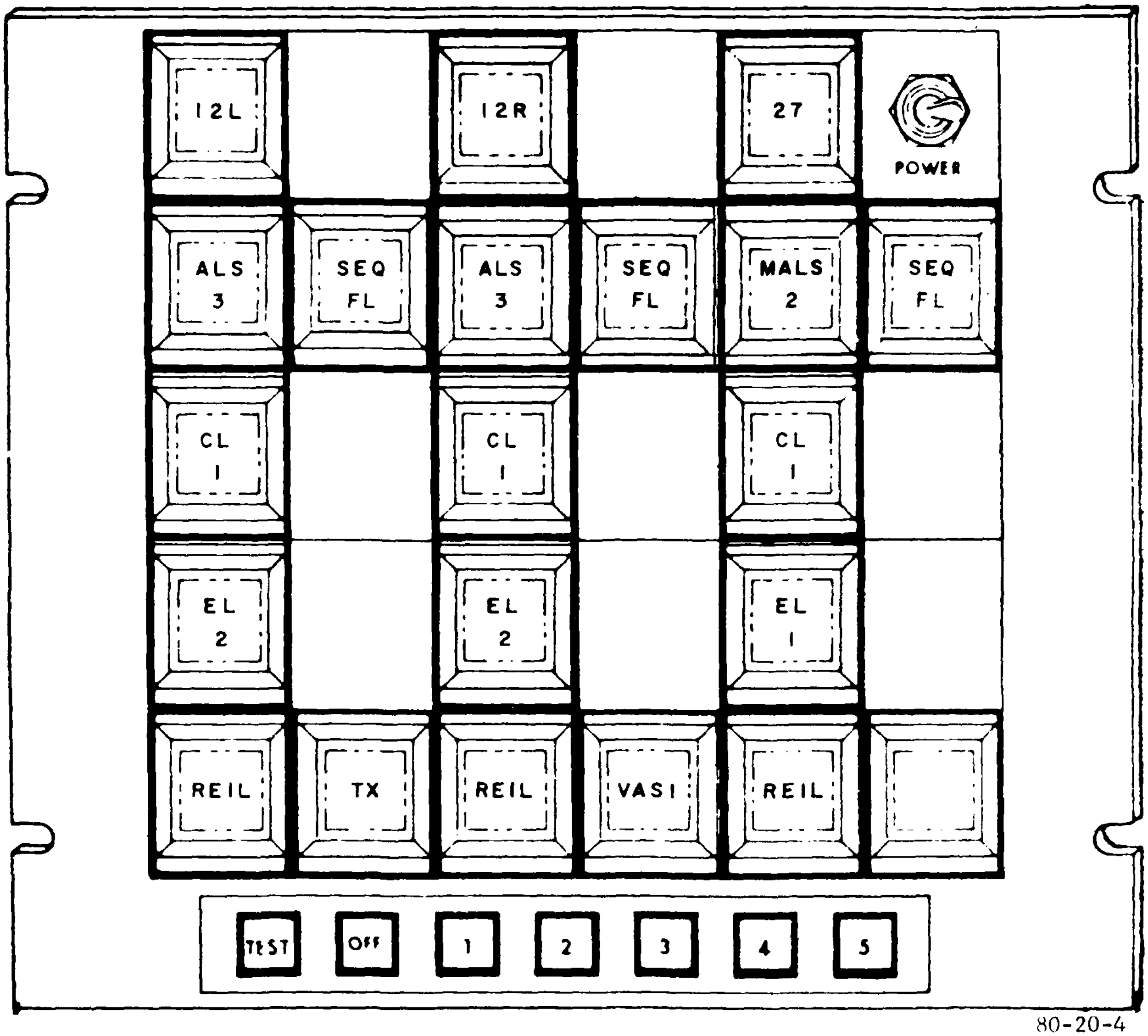
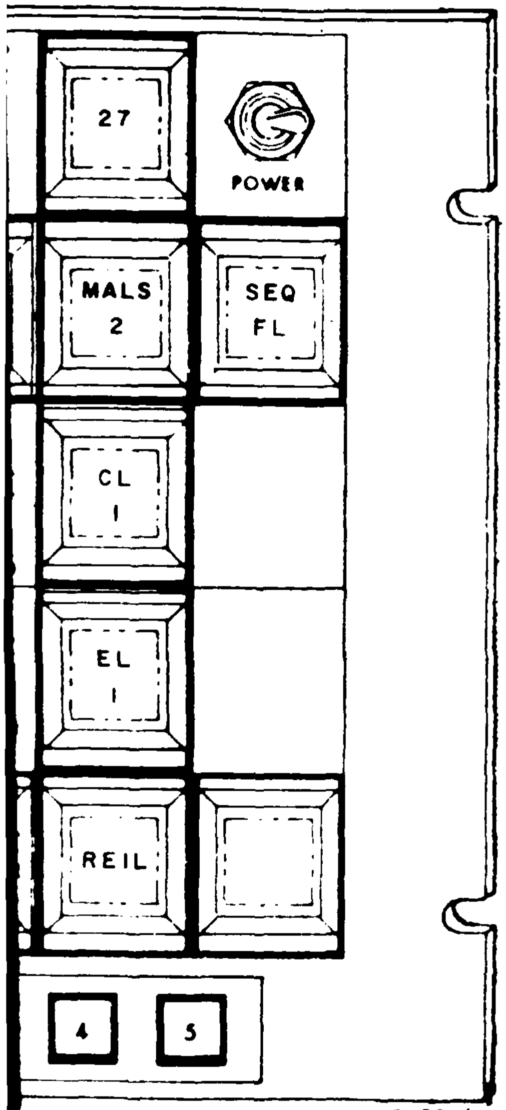


FIGURE 4. LIGHTING CONTROL PANEL (FULL SCALE)



LEGEND

12L 12R 27—RUNWAY NUMBERS
CL—CENTERLINE (RUNWAY)
EL—EDGE LIGHTS
REIL—RUNWAY EDGE ILLUMINATION LIGHTS
SEQ FL—SEQUENCE FLASHER
TX—TAXIWAY LIGHTS
VASI—VISUAL APPROACH SLOPE INDICATOR
ALS—APPROACH LIGHTING SYSTEM
MALS-MANUAL LIGHTING SYSTEM

FIGURE 4. LIGHTING CONTROL PANEL (FULL SCALE)

APPENDIX A

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